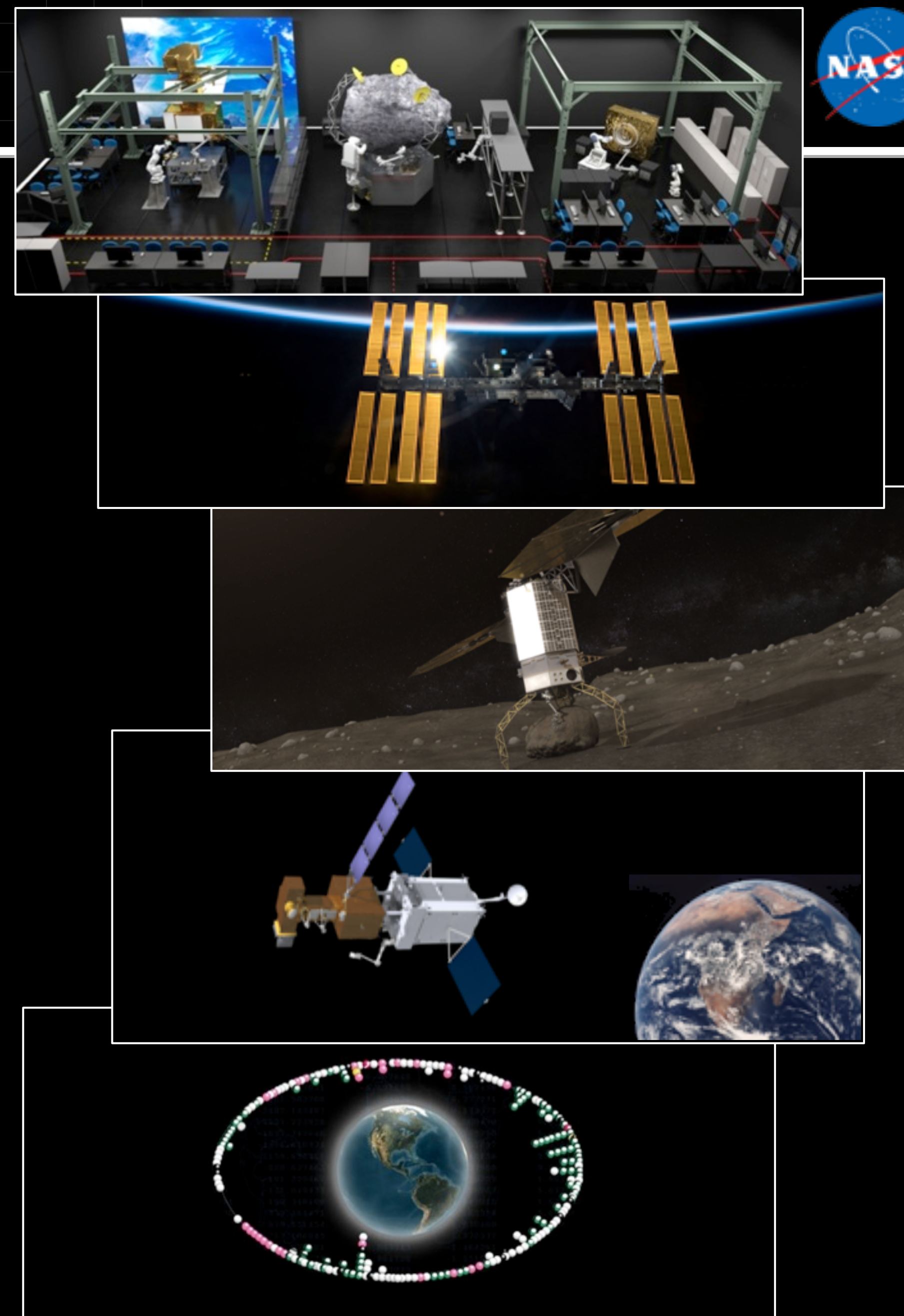
Spacecraft Modularity for Serviceable Spacecraft



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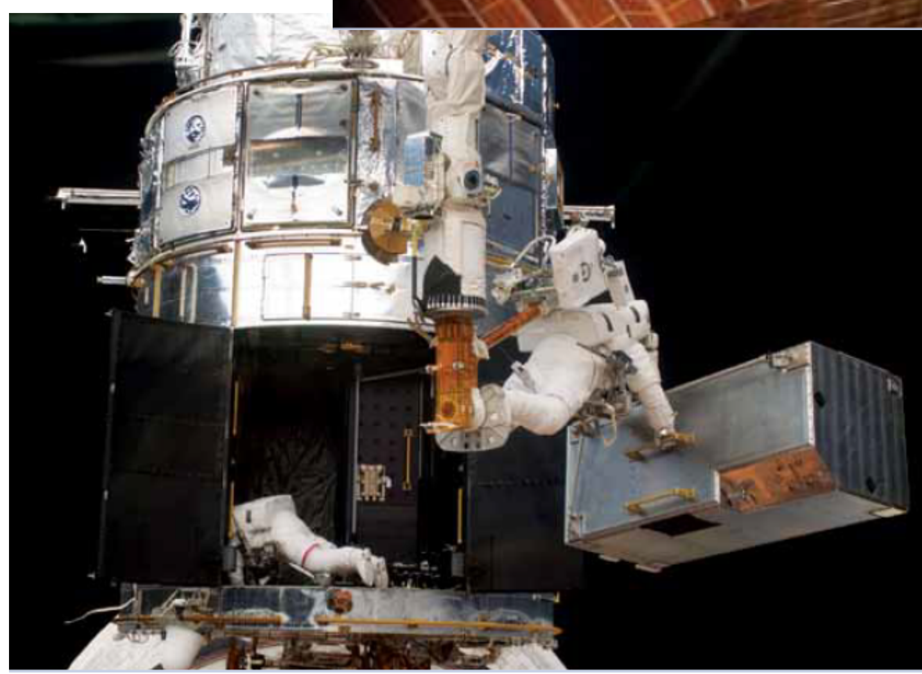
Introduction: Modularity

- Modularity – the degree to which a system's components may be separated and recombined

Highly integrated, serviceable with extreme difficulty

Highly modular, easily serviceable

Introduction: On-Orbit Servicing



Overview: On-Orbit Servicing

Complexity

Goals	Type of Servicer (Human/Robotic)	Type of Client	
Mission Enabling	Robotic autonomous	Cooperative	Facility Class
Repair/ Enhancement	Robotic teleoperated	Non-cooperative	Small
Life extension	Human		
	Human + robot		

On-orbit servicing missions vary along multiple parameters.

Goals of On-Orbit Servicing

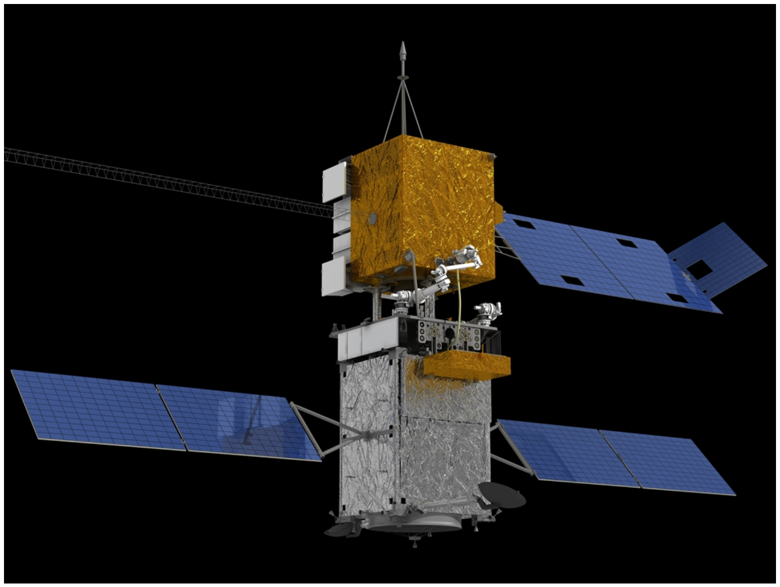
Higher Value/
Higher Cost

Lower Value/
Lower Cost

- Mission Enabling
  - Missions that would not be possible without on orbit servicing activities
  - Examples: ISS, future life finder telescope
- Repair / Enhancement
  - On-orbit servicing to repair (i.e. salvage) or improve existing missions
  - Examples: HST, SolarMax, Intelsat VI
- Life Extension
  - On-orbit servicing to extend the life of existing missions
  - Examples: Future on-orbit refueling

Type of Servicer

Robotic
(teleoperated, autonomous)



- Avoids putting humans at risk
- Can go where humans presently cannot go
- Historically in conjunction with astronauts
- Advances in capabilities are ongoing
- Works best with known interfaces

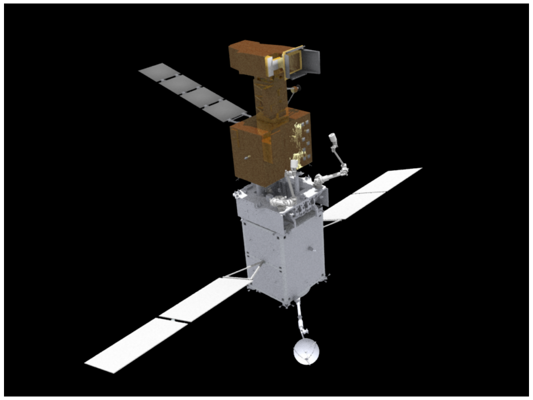
Astronauts
(with and without robot)

- Astronaut dexterity and tactile sensing far surpass current robotic capabilities
- Especially important for complex interfaces (non-cooperative S/C)

Astronauts and robots working together bring the highest capabilities to servicing tasks.

Type of Client

	Cooperative	Non-Cooperative
Facility Class	Examples: HST Types of servicing: Life extension, repair, enhancement Complexity: Low	Examples: Landsat 7 Types of servicing: Repair, life extension Complexity: High
Smaller	Examples: MMS, ROSE Types of servicing: Module replacement and/or life extension if multi-sortie mission Complexity: Low	Examples: Most existent SC Types of servicing: life extension (refueling), repair Complexity: High



Aspects of Cooperative Clients

Mission Element	Serviceable	Highly Cooperative
Rendezvous	Optical targets	RF crosslink
Capture	Reference markings	Grapple and standard docking features
Life Enhancement (Refueling)	External valve labels	Robotically compatible valves
Repair / Upgrade	Planned accessibility	**Modular design** **Robotic interfaces**

Modularity is a key aspect for cooperatively serviceable spacecraft.

Spacecraft Modularity

For our purposes, modularity in spacecraft has three key aspects:

- having units with relatively simple interfaces that can be easily removed and replaced,
- *grouping of components into these units, <u>and</u>*
- the standardization of unit (module) designs

Building blocks are important, but all of these aspects are relevant for spacecraft modularity.

Modularity Spectrum

Typical Spacecraft Bus

- Many individual components
- Optimized for mass
- Specialized interfaces
- Single line I&T flow
- No easily serviceable interfaces

Minimally Modular Bus

- Components collected into a small number of large modules.
- Allows parallel I&T flows.

e.g. Commercial Communications Satellite Families

Serviceable Modularity

- Some components grouped for servicing/I&T
- Some standardized interfaces
- Parallel I&T flows
- Accommodates servicing – some complexity

e.g. HST, ISS

High Level Modularity

- Components grouped into replaceable modules
- Highly standardized interfaces
- Parallel I&T flows - increased flexibility
- Accommodates servicing – minimal complexity

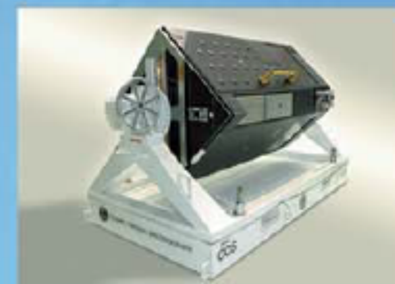
e.g. MMS, ROSE

Highly Integrated → *Highly Modular*

Serviceable Modularity: HST

- HST was designed from the ground up with servicing in mind
- Many components designed to be manipulated on orbit
  - Some component grouping and standard interfaces
- HST still lacked high level component grouping and interface standardization.
  - Complex, customized servicing tools and procedures

Wide Field Camera 3 (WFC3)
Into Aft Shroud Radial Bay



Cosmic Origins Spectrograph (COS)
Into Aft Shroud

Six batteries
Into Bays 2 and 3

Three Rate Sensor Units (RSU)
Into Aft Shroud

ORUs Replaced During HST SM4

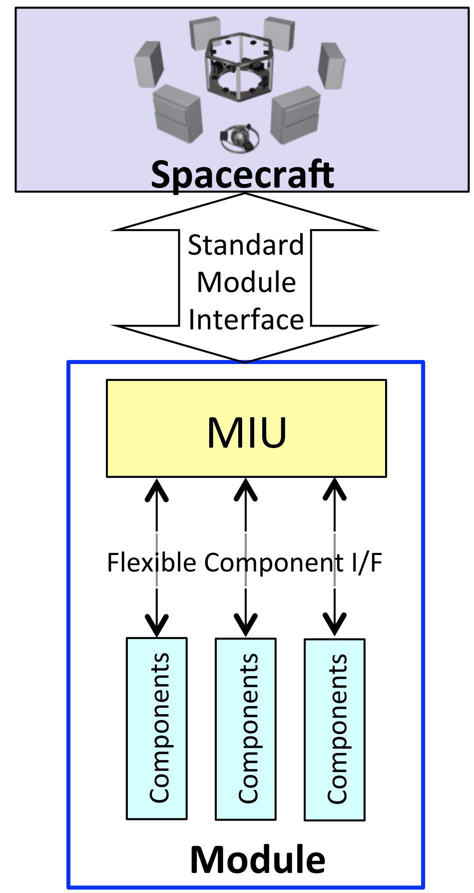
Science Instrument Command and Data Handling (SI C&DH) unit
Into Bay 10

High-Level Modularity: MMS

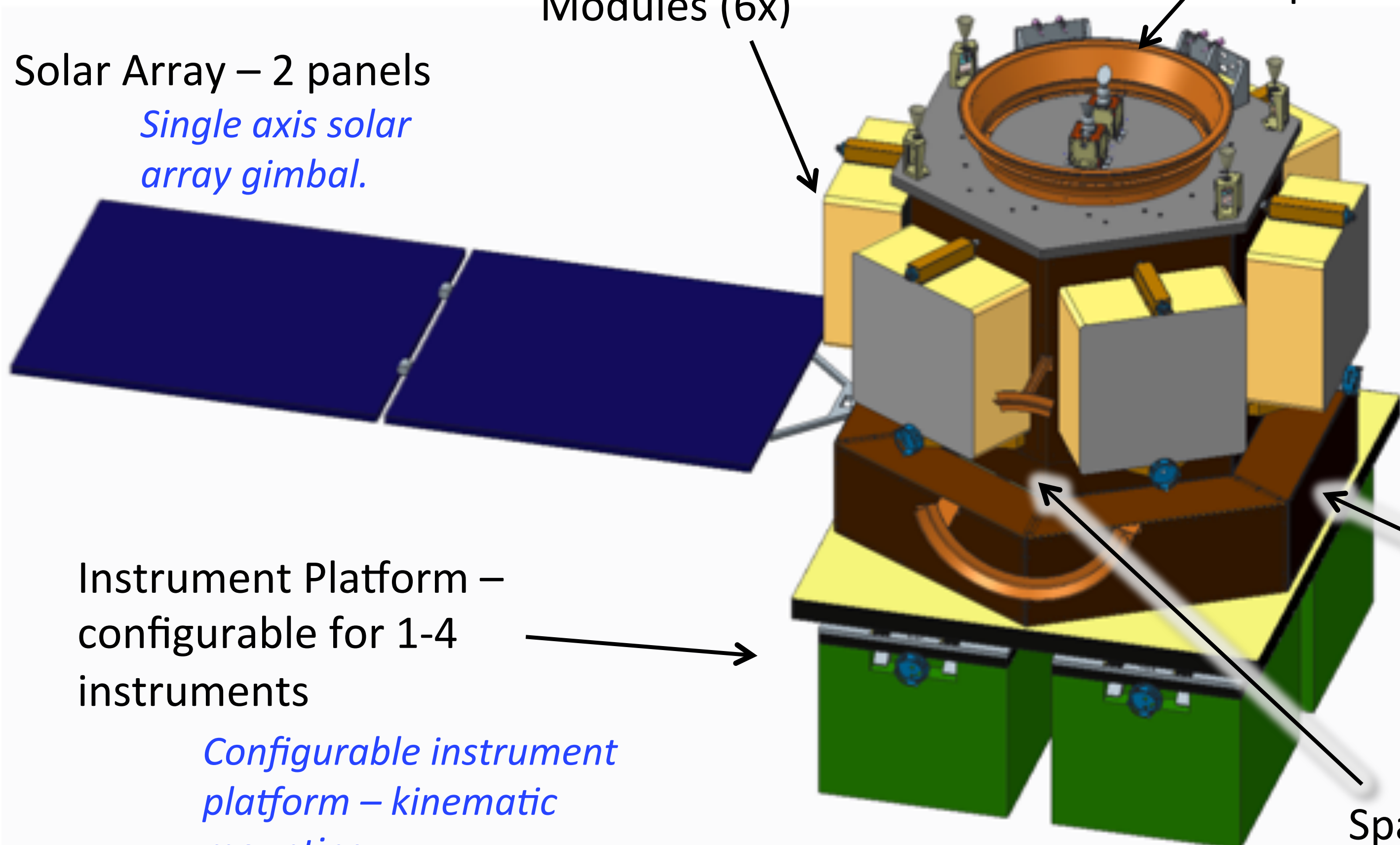
- Components grouped into serviceable modules (e.g. subsystem level)
- Standard module designs – especially interfaces → reduced GSE Costs
- Highly parallel module I&T flows and simplified spacecraft I&T → reduced I&T schedule and budget, increased flexibility

ROSE: Objectives

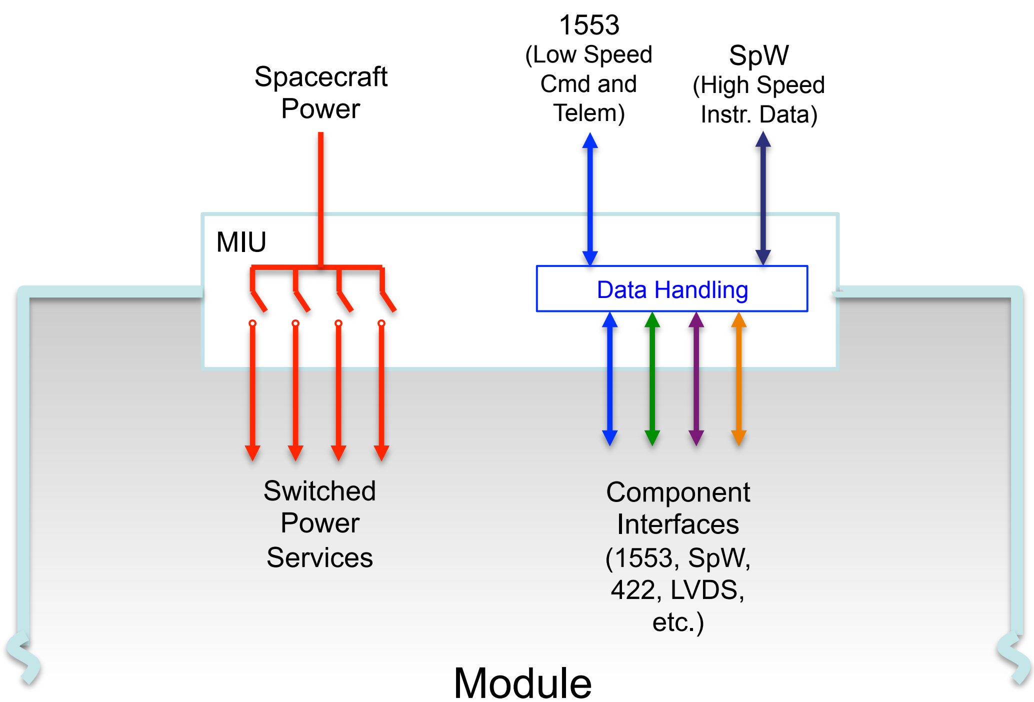
- MMS demonstrated the cost benefits of modularity
- ROSE seeks to improve on the MMS example by bringing in state-of-the-art technology
- Modularity = Flexibility + Affordability
  - Standard module interface provides flexibility
  - Component changes are isolated to the module – do not impact full system
  - Provides customization, technology infusion and least cost component selection with minimal NRE
  - Commercial competition at the module level
- ROSE takes advantage of all of the I&T benefits of modularity



ROSE Spacecraft Overview

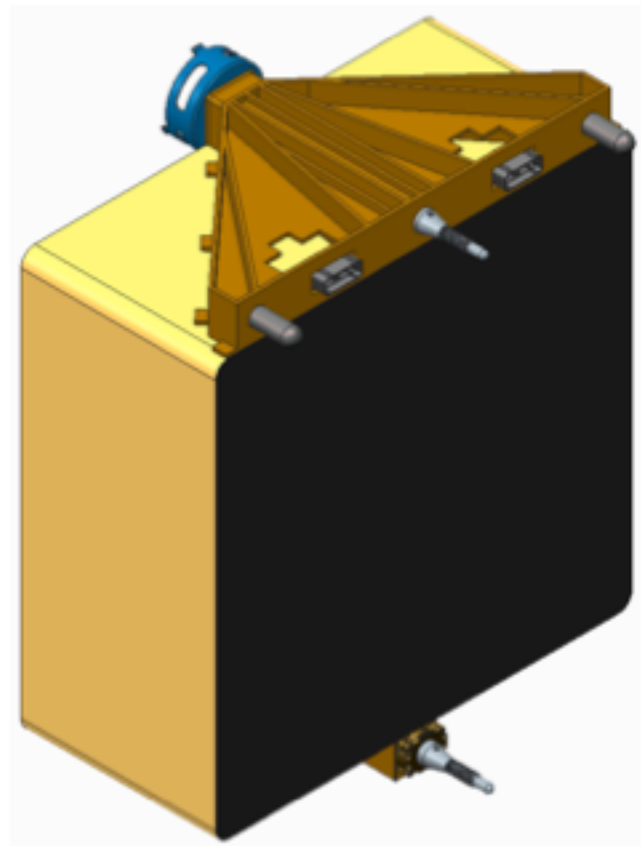


ROSE Modularity



- Each module contains a standard Module Interface Unit (MIU)
- MIU provides power management, command and telemetry interfaces
- Flexible component interfaces

- Standard module mechanical design with robotically compatible interfaces



Conclusions

- Throughout NASA's long history of on-orbit servicing, modularity has played a key role in spacecraft designs
- Modularity and serviceability go hand in hand. Cooperative spacecraft allow for high value servicing missions with minimum complexity, risk and cost.
- The modular ROSE spacecraft architecture is designed for flexibility and affordability
  - The modular design provides maximum flexibility for component selection
  - The same design attributes also make ROSE a highly cooperative spacecraft for on orbit servicing

http://bit.ly/1PA8feJ

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